Utility Views on Control Room Habitability Analysis and Testing

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Purpose

This paper provides Duke Energy Corporation's perspectives on the interactions between the radiological accident analyses required for control room operator dose calculations and the testing programs for control room unfiltered air inleakage. Substantial improvements have been made in both the analysis approaches available to utilities and the understanding of effective testing protocols and test data evaluation.

Duke Energy Corporation has participated on the industry's Nuclear Energy Institute Control Room Habitability (CRH) Task Force activities in the Analysis & Assessment and Systems Subgroups since 2000. Industry has worked through these teams with the NRC to improve the way in which these issues can be addressed. In the presentations and panel discussions that follow in this conference session, additional details regarding the provisions of the control room dose calculation approaches will be outlined. To summarize for the discussion in this paper, the interaction between the CRH Task Force Analysis & Assessment Subgroup and the NRC have resulted in a number of enhancements to the analysis approaches and methods. These new tools can provide more realistic results and a better understanding of the control room ventilation system performance, which generally leads to greater flexibility in managing performance issues for these plant systems.

Control Room Tracer Gas Testing Experience at Oconee Nuclear Station

Two campaigns of control room inleakage tracer gas testing were conducted in 1998 and 2001 at the Oconee Nuclear Station (ONS). Both test programs were performed by NCS Corporation and Lagus Applied Technology, Inc. The testing in June 1998 was the first quantitative, integrated evaluation conducted at the site to ascertain the general performance of the system following an initial campaign of sealing and repair. Measurements of overall control room inleakage were developed and evaluated. System improvements and sealing work were performed between the 1998 and 2001 tests. The purpose of the testing work in August 2001 was to demonstrate the effectiveness of this Control Room Ventilation System sealing program.

Additionally, reviews of the test data from the 1998 campaign suggested improvements that could be made in the testing setup and protocol to improve the accuracy of the results. These developments were based on the testing performed and analyzed at ONS in 1998, as well as on additional control room testing experience by NCS Corporation and Lagus Applied Technology, Inc in the interim. The most important finding was that system flow measurements could be improved substantially by ensuring that enhanced mixing of the tracer gas was achieved in the ductwork. The assumption made in the 1998 testing protocol was that right-angle turns in the ductwork in high flow streams would induce sufficient mixing for accurate flow measurement. The performance of turning vanes to prevent mixing in short ductwork lengths was underestimated and this was found to confound the results, especially when tracer gas injection across the ductwork was non-uniform.

In particular, the following major features were added to the 2001 testing approach:

- Tracer gas mixing was augmented by incorporating advanced flow sparger designs for tracer gas injection and mixing fans in the flow stream to assure more accurate and repeatable sample measurement in the flow stream.

- Injection and sampling locations for flow measurements were modified to obtain more uniform tracer gas mixing in the flow stream at the sampling points.

- Calculation of measured values and uncertainties was augmented to evaluate uncertainty associated with data sets with data values clustered about a zero inleakage value.

The tracer gas injection location for the 2001 test is shown in Figure 1. A gas injection flow sparger was installed at the location of the control room air intake on the building roof. Figure 2 is a view into the intake ductwork showing the turning vanes prior to installation of the tracer gas test mixing equipment. The distribution and mixing system for the test injection is shown in Figure 3, with a view into the intake duct. The tracer gas sparger design is seen to provide a distribution of tracer gas flow across the duct area at the point of injection. Further, small counter-current mixing fans were included as part of the temporary injection system to assure that the tracer gas was fully mixed across the flow stream prior to passing across the turning vanes below.

This setup is compared to the one used in the 1998 test, where the tracer gas injection point was into three ports through the bottom of the intake ductwork in the ventilation equipment room, clearly further along the ducting route and away from the air intake. These locations are shown in Figure 4, where the 1998 injection ports are seen to be at the top of the column in the upper right of the photograph (at about the same elevation as the upper run of conduit). The sample ports for both the 1998 and 2001 tests are on the bottom of the duct at the lower left of the photograph. As discussed above, this setup allowed only a short distance between the injection and sample points for the 1998 test. This also contributed to the inability to derive consistent measurements of flowrate.

Sample pump and tubing for the testing of the systems in ventilation equipment room are shown in Figure 5. Also shown here are the results of the sealant work on the filter unit and ductwork. Figure 6 shows the results of the sealant work on the Air Handling Unit access door and seams.

Table 1 displays the comparison of the results from the 2001 test versus the 1998 test for all measurement categories, which demonstrates that the sealing program made a significant improvement in system performance. The primary testing configurations for each of the two ONS control rooms are (1) in the normal mode of operation prior to initiation of the emergency pressurization system, (2) in the emergency mode with one fan in operation, and (3) in the emergency mode with two fans in operation. All measured nominal testing results showed improvement. The changes in testing protocol, combined with the sealing program improvements, resulted in data sets that exhibited lower deviation in testing measurement within each test and between comparable tests. In all cases the uncertainty derived from the testing data was lower for the 2001 test campaign.

Calculations for Control Room Operator Dose under Accident Conditions

Duke Energy Corporation maintains a corporate radiological engineering program staff to perform evaluations of accident conditions and the potential impacts on offsite and control room dose. The program plan related to improving understanding of the control room ventilation system performance includes analyses and testing for the ONS site, as well as for the Catawba Nuclear Station and McGuire Nuclear Station sites. ONS has been the lead site for this analysis effort and testing program. The primary analyses methodology for evaluation of the control room dose employs the LOCADOSE and ARCON96 computer codes.

The LOCADOSE code system (Reference 1) is designed to calculate radioactive isotope activities within regions, radioactive releases from regions, and dose and dose rates for plant personnel and equipment, as well as offsite doses to the general public. The program was selected for use by Duke Energy Corporation because of its broad modeling capabilities, as well as its extensive code verification and validation experience basis. The code supports applications using either the traditional TID-14844 accident source term (Reference 2) or the Alternative Source Term (AST), as described in the NRC Regulatory Guide 1.183 (Reference 3). For the purposes of this ONS project Duke Energy Corporation applied the AST technology feature. Other modeling approaches are being developed by the NRC and industry that can amplify current licensee approaches using traditional source term methods to take advantage of some of the technology improvements developed for application in Regulatory Guide 1.183. (References 4 and 5)

The ARCON96 computer code (Reference 6) is used to determine the dispersion of the radioactive plume from site release points and the resulting concentration at the control room intake. The methods of approach that have been used were also enhanced through NRC and industry interactions in the CRH Task Force/NRC meetings (References 4 and 7). Advantages attributable to ARCON96 result from the model development using detailed meteorological field data. As such, the applications generally show improved performance over earlier models in predicting the effect of building wakes, particularly under light wind conditions.

Duke Energy Corporation completed the evaluations of control room operator dose using these methodologies in October 2001 and submitted the work to the NRC for review and approval (Reference 8). The NRC has completed a majority of that review, which has included a Request for Additional Information and subsequent responses by Duke in May 2002. The measurement results from the 2001 test set were not available when this License Amendment Request was submitted to the NRC for review. Therefore, the data sets for unfiltered Control Room inleakage used in that original submittal analyses were derived from the 1998 tests. The comparisons of the data obtained in the 1998 and 2001 test campaigns are presented in the tables below. The impacts of these improvements in testing results on the Control Room dose evaluation are then discussed.

Control Room Unfiltered Air Inleakage Analysis Input Assumptions Based upon Testing Results

The measured inleakage values, with uncertainty, obtained from 1998 tracer gas testing are shown in Table 2. The unfiltered inleakage values used in the proposed licensing analyses approach are also included.

The measured inleakage values, with uncertainty, obtained from 2001 tracer gas testing are shown in Table 3. The unfiltered inleakage values used in the proposed licensing analyses approach are also included.

The methodology used in the testing and analyses follows that described in References 9 and 10. The referenced ASTM Standard E 741-95 was in process of development and review at the time of the 1998 testing. However, the protocol outlined in Reference 9 was followed. This protocol served as part of the basis for the guidance developed in the Standard, and the test method used is consistent with it. Except for the improvements noted in the section on testing above, there were no fundamental differences in the performance of the 1998 and 2001 ONS tests.

For the 1998 test results, the total uncertainty of each CRE air inleakage measurement is calculated using the prescription provided in ANSI/ASME Standard PTC 19.1-1985 "Measurement Uncertainty" and represents 95% confidence limits. The same method was applicable to the measurement of inleakage for the configuration in the "Normal" ventilation mode in the 2001 test data evaluation. For the analyses of the Emergency ventilation mode the uncertainty values were determined using a different application of the statistical *T*-test (Students t or Fisher's "*t* test of significance for differences between sample means"). First, the statistical test is used to ascertain if the test data demonstrate that the testing result is different than zero inleakage. If it does not satisfy this statistical test condition, then the measured response is zero inleakage. The uncertainty value is then calculated as that value of the mean difference that satisfies the statistical test condition with the corresponding degree-of-freedom (7 or 8) and confidence level (95%).

As shown in the tables of results, the Control Room unfiltered inleakage values chosen for the licensing analyses that have been presented in the ONS licensing amendment request submittal to the NRC bound the nominal test values plus the upper bound value of the uncertainty range for both the 1998 and 2001 tests. For each test the values chosen also bound the sum of (1) the nominal test results and (2) a 10 CFM allowance for unfiltered inflow due to Control Room ingress and egress during the course of an accident.

Duke Energy Corporation has concluded that the appropriate input values for unfiltered inleakage as derived from these test results should correspond to the nominal values determined from each of the testing programs. This conclusion is valid because the uncertainty values derived from the experimental results are within a reasonable range, as seen in the data set measurement results shown above. For the 2001 test results the range of calculated uncertainty is between 13 and 31 CFM, so that the nominal measured values of inleakage (0 CFM) should be used. This value to be used for analyses will be augmented by a 10 CFM allowance for unfiltered inflow due to Control Room ingress and egress throughout the course of an accident.

The selection of bounding values for the analyses as described above provides Duke with margin to accommodate changes in input assumptions that could be required to account for possible plant operational changes, such as increases in ECCS system leakage flow, imbalances in ventilation system flowrates, or reductions in filtration efficiencies. When these analyses are required, Duke will include additional margin in the input value for unfiltered inleakage of 15 CFM in the Emergency mode to account for potential unfiltered inleakage performance degradation. Therefore, the unfiltered inleakage values used for these analyses, based upon the modified 2001 results, will be no less than 880 CFM for normal ventilation operation and 25 CFM for the Units 1&2 Emergency - 1 Fan operation.

Sensitivity of Analysis Results to Control Room Unfiltered Air Inleakage Analysis Input Assumptions

Table 4 demonstrates the sensitivity of the results for the Control Room dose for representative sets of unfiltered inleakage values. The operation of the Emergency CR Fan at ONS requires manual action. Therefore, in the evaluation of performance for the ONS CR emergency ventilation system, the analysis assumes that the CR remains in the Normal ventilation system mode for the first 30 minutes following the initiation of an event. At 30 minutes the Emergency - 1 Fan operation is assumed to begin. Inleakage values during these time periods are assumed accordingly. For the LOCA evaluation the analyses for both ONS control rooms were performed using the limiting case values. These are the values shown in Tables 2 and 3 for the Units 1&2 Control Room. For the licensing case, or Bounding Case, the values are those derived from the 1998 testing, or 1150 CFM for the Normal ventilation system mode and 150 CFM for the Emergency - 1 Fan ventilation system mode. The margin in the results of this case to the 5 rem Total Effective Dose Equivalent (TEDE) limit is almost 2 rem TEDE.

The Base Case results are calculated using the unfiltered inleakage input values derived from the 2001 testing, where the Emergency - 1 Fan operation corresponds to a value six times lower than for the Bounding Case. Control room dose values over the course of the 30-day event evaluation are improved by almost a factor of three.

To further understand the relationship of the dose results to the variation in the input values, the Augmented Bounding Case demonstrates that even when the input set is specified with inleakage values 50% greater than the Bounding Case and almost 10 times the Emergency mode inleakage value for the Base Case, dose values are predicted to be within limits.

The final sensitivity study, labeled Ventilation Mode, demonstrates that the dose prediction is most sensitive to this post-booster fan value (after 30 minutes into the accident). In particular, doubling the value of the inleakage during the period prior to booster fan operation for the Bounding Case (to 2300 CFM), while holding the Emergency Ventilation mode value at 150 CFM, results in an increase in total dose of only 0.2 rem TEDE. This result is expected because of the relative amounts of radioactivity available for intake before and after the 30 minute switchover time.

Further studies at Duke Energy Corporation have demonstrated the importance of evaluating sensitivities of the CR dose analyses results to assumptions in ventilation system parameters (Reference 11). Most licensees are performing more detailed calculations that capture more realistic estimates of the timing and content of the radioactivity release with Alternative Source Term implementation. These changes in analysis approach may affect some Rules of Thumb or expectations that have been developed from more conservative analysis models. With these changes for some accident scenarios, the primary contributors to whole body dose may be noble gases versus forms of iodine, so that assumptions regarding the effectiveness of filtration systems or the worst case limiting flowrate assumptions for ventilation intake and recirculation systems may need to be reexamined.

References

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10. American Society for Testing and Materials, *Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution*, ASTM Standard Designation: E 741-95, December 1999.

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Table 1			
Results from ONS Tracer Gas Testing Performed in 1998 and 2001			
Control Room	**Testing Configuration**	**1998 Measured Inleakage Values**	**2001 Measured Inleakage Values**
U1/U2	Normal	1065 +/- 61 ACFM	869 +/- 31 ACFM
U1/U2	Emergency 1 Fan	80 +/- 55 SCFM*	0 +/- 18 SCFM*
U1/U2	Emergency 2 Fan	[0 - 128] SCFM*	0 +/- 30 SCFM*
U3	Normal	534 +/- 30 ACFM	467 +/- 16 ACFM
U3	Emergency 1 Fan	73 +/- 25 SCFM*	0 +/- 13 SCFM*
U3	Emergency 2 Fan	[0 - 236] SCFM*	0 +/- 39 SCFM*

Notes: * Referenced to 70 Deg F and 14.7 psia

Control room pressurization system performance improvement was evident in the 2001 testing

Table 2			
Measured Inleakage Values from the 1998 Testing: Comparison with Analyses Inleakage Values			
Control Room	**Ventilation Mode**	**Measured Inleakage Values**	**Analyses Inleakage Values**
U1/U2	Normal	1065 +/- 61 ACFM	1150 CFM
U1/U2	Emergency 1 Fan	80 +/- 55 SCFM*	150 CFM
U3	Normal	534 +/- 30 ACFM	600 CFM
U3	Emergency 1 Fan	73 +/- 25 SCFM*	100 CFM
* Referenced to 70 Deg F and 14.7 psia			

Table 3			
Measured Inleakage Values from the 2001 Testing: Comparison with Analyses Inleakage Values			
Control Room	**Ventilation Mode**	**Measured Inleakage Values**	**Analyses Inleakage Values**
U1/U2	Normal	869 +/- 31 ACFM	1150 CFM
U1/U2	Emergency 1 Fan	0 +/- 18 SCFM*	150 CFM
U3	Normal	467 +/- 16 ACFM	600 CFM
U3	Emergency 1 Fan	0 +/- 13 SCFM*	100 CFM

* Referenced to 70 Deg F and 14.7 psia

Table 4				
Sensitivity of the Calculated Control Room LOCA Dose as a Function of Assumed Unfiltered Inleakage Input Parameters				
Case Description:	**Base Case 2001 Test Basis**	**Bounding Case 1998 Test Basis**	**Augmented Bounding Case**	**Ventilation Mode Sensitivity**
Inleakage Ventilation Mode Normal	880 CFM	1150 CFM	1725 CFM	2300 CFM
Inleakage Ventilation Mode Emergency 1-Fan	25 CFM	150 CFM	225 CFM	150 CFM
Containment Dose (rem)	0.9	2.5	3.4	2.7
ECCS Dose (rem)	0.2	0.6	1.0	0.6
Total Control Room Dose (rem TEDE)	**1.1**	**3.1**	**4.4**	**3.3**

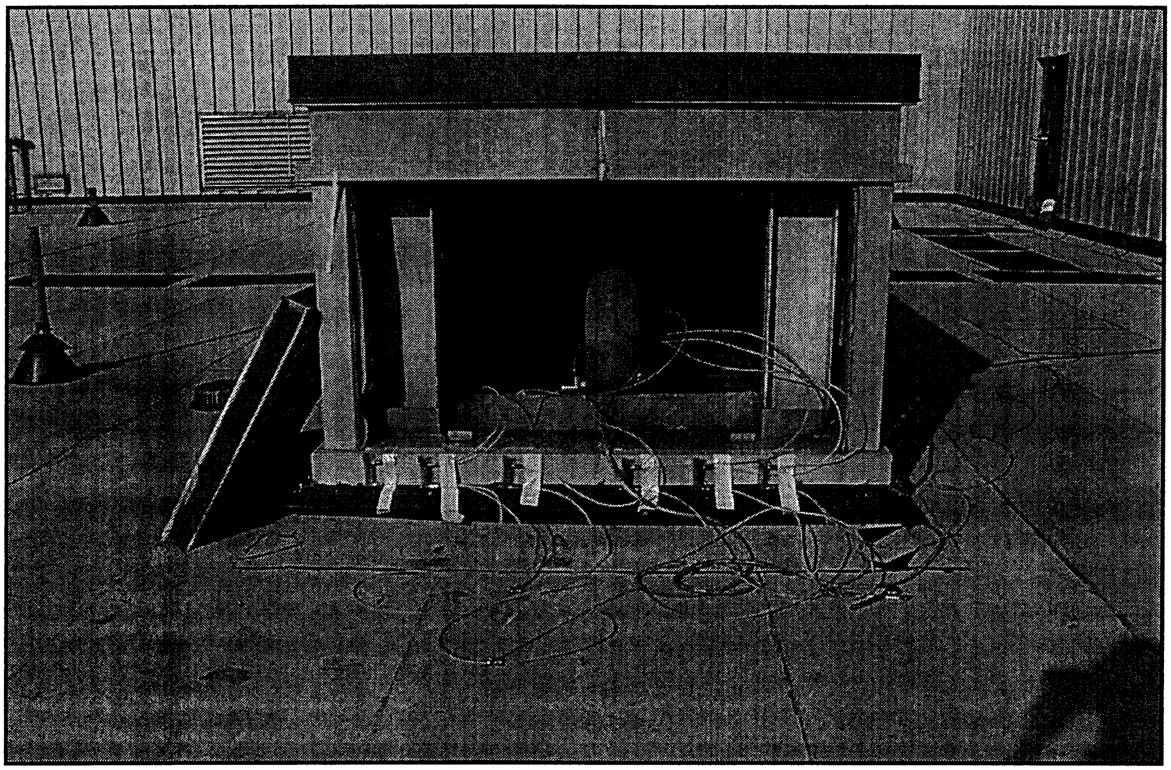

Figure 1 Gas injection tubing at outside air intake for ONS Units 1 & 2.

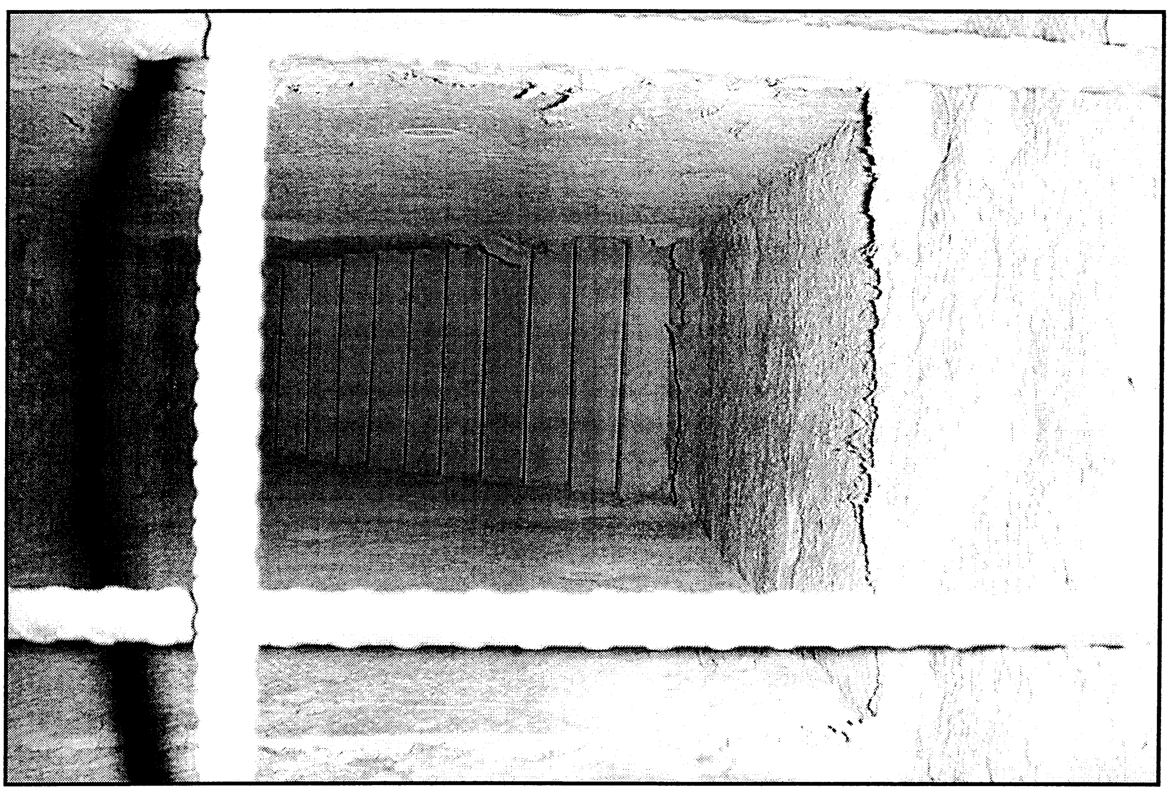

Figure 2 Control Room Ventilation System Outside Air Intake for ONS Units 1 and 2. Turning Vane at 52 in. down into duct.

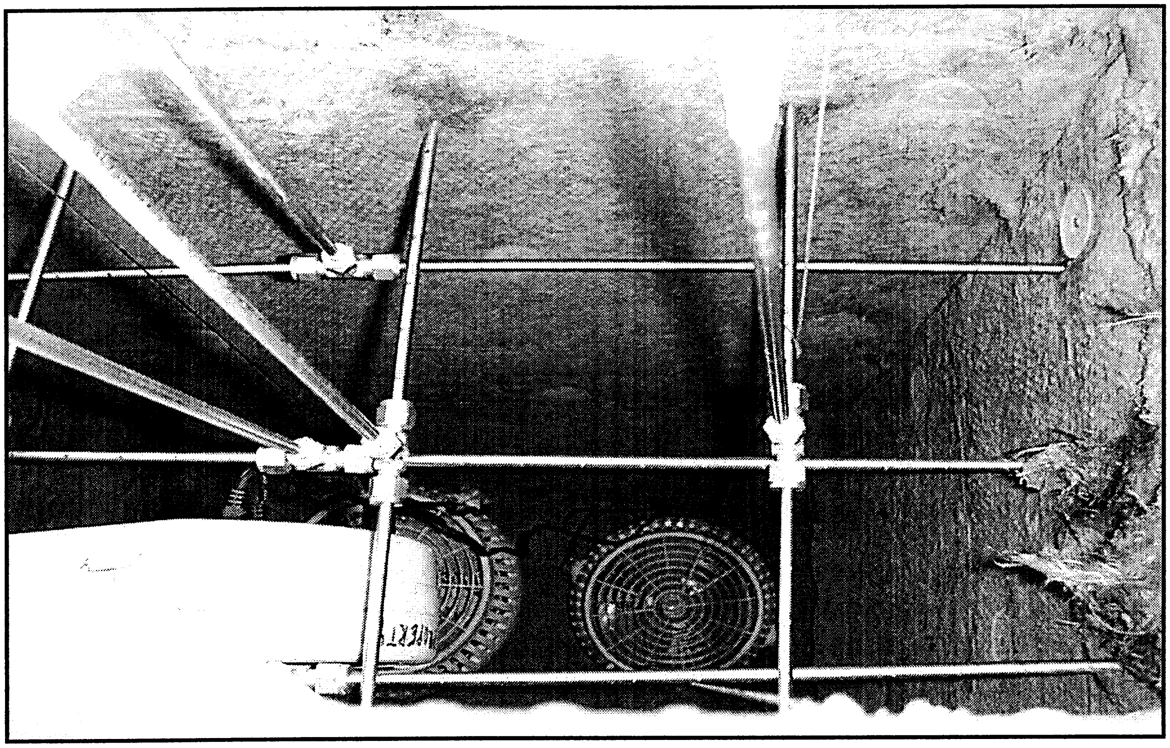

Figure 3 Control Room Ventilation System Outside Air Intake with gas injection manifold inside duct and fans to promote mixing.

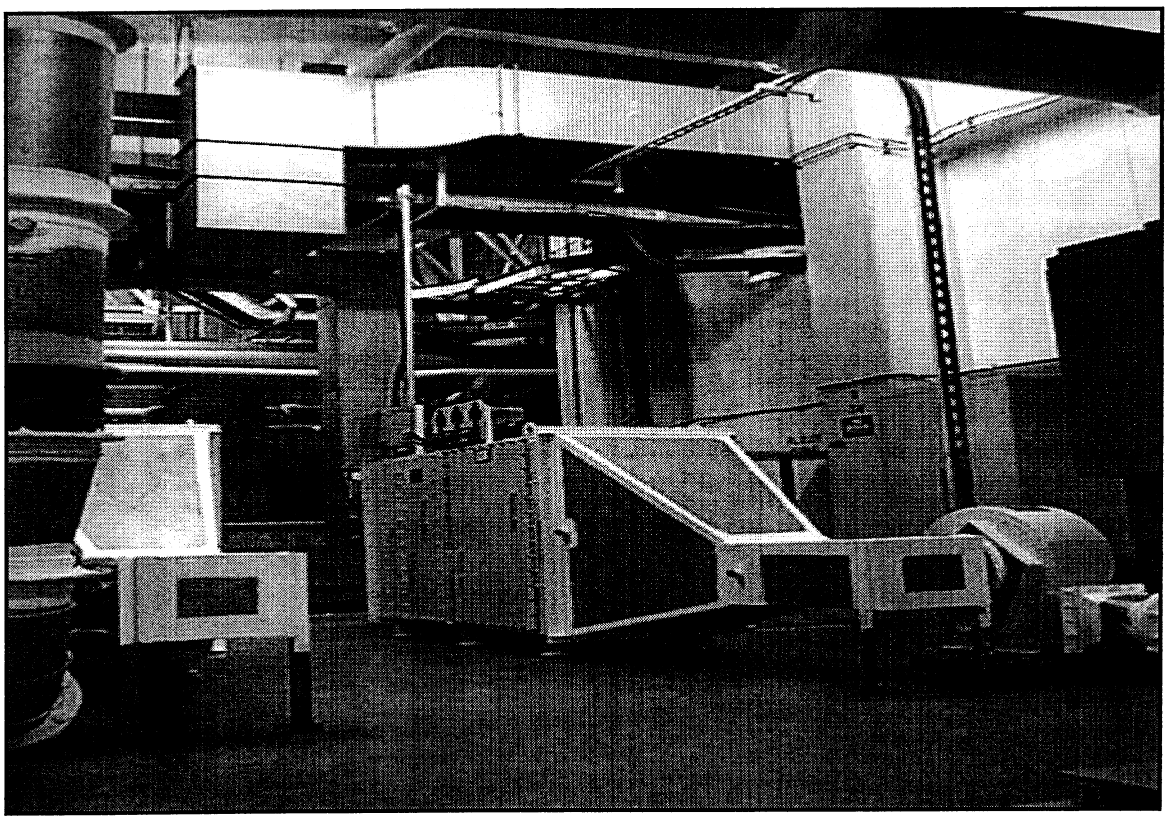

Figure 4 Ductwork at inlet of Unit 1 & 2 CR filters. Injection Ports for the 1998 test are at the column (upper right) and the sample ports are on the bottom of the duct (lower left), allowing a short distance between the injection and sample points. Gas injection for the 2001 test was at the outside air intake on roof.

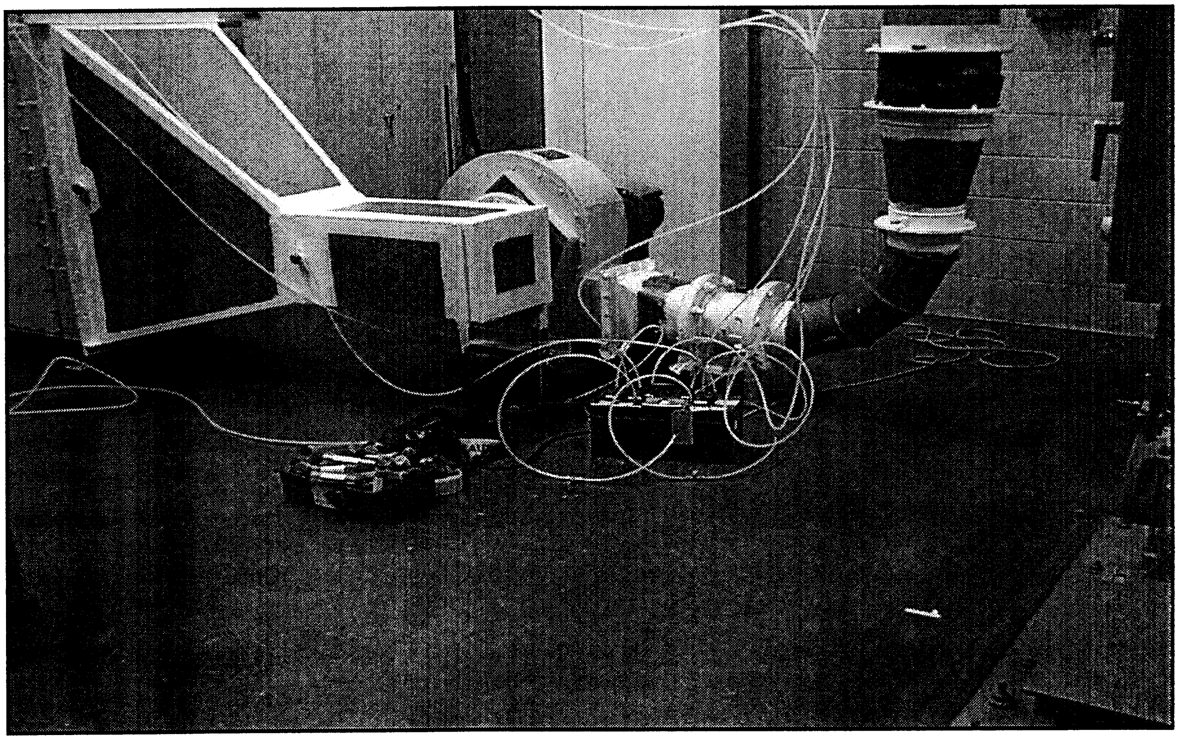

Figure 5 Sample pump and tubing in ventilation equipment room. Note sealant on filter unit and ductwork.

Figure 6 Air Handling Unit access door showing sealant work.